Two Mechanism-Based Approaches to Predict Ductile Fracture

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Micromechanics analysis of the fracture process makes it possible to link the macroscopic fracture toughness and the microstructure of the material. Ductile fracture of many structural materials is a result of void nucleation, growth and coalescence. Therefore, development of predictive fracture models for risk assessment of structural components requires analytical and numerical modeling of the void nucleation, growth and coalescence process. We employ two types of mechanism-based approaches to model the material failure process and to simulate crack propagation in ductile solids. In the first approach, voids are considered explicitly and modeled using refined finite elements. A distinct advantage of this approach is the exact implementation of the void growth behavior. In order to establish crack advance, a failure criterion for the ligament between a void and the crack tip is required, which can be obtained by conducting systematic finite element analyses of the void-containing, representative material volume (RMV) subjected to different macroscopic stress states. This approach is suitable to study the void growth and coalescence mechanisms and to reveal the trends of fracture toughness of materials [1]. However, due to sizeable difference between the characteristic length scales involved in the material failure process and the dimensions of the actual structural component, it is impractical to model every void in detail in structure failure analysis, especially for situations involving extensive crack propagation. For this reason, various forms of porous material models have been developed to describe void growth and the associated macroscopic softening during the fracture process. Calibration of these porous material models requires the predicted macroscopic stress-strain response and void growth behavior of the RMV to match the results obtained from detailed finite element models with explicit void representation. In the second approach, voids are considered implicitly by using porous plasticity models. A numerical approach based on the Gurson-Tvergaard model [2] was proved to be very effective for thick sections and high-constraint conditions where voids are essentially spherical. For many processed materials, such as rolled plates, voids are not spherical. The Gologanu-Leblond-Devaux model [3] provides a constitutive relation for growth of non-spherical voids. Since non-spherical voids are considered in the constitutive model, preferred material orientation exists and the plastic behavior becomes anisotropic. We present a general approach for numerical implementation of complicated plasticity models [4]. The second approach is attractive for simulation of extensive crack growth because detailed modeling of each individual void is avoided. As an example, a numerical approach is proposed to predict ductile crack growth in thin panels of a 2024-T3 aluminum alloy, where a porous plasticity model is used to describe the void growth process and the material failure criterion is calibrated using experimental data. The calibrated computational model is applied to predict crack extension in fracture specimens having various initial crack configurations. The numerical predictions agree very well with experimental measurements.

References

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